Some Thoughts about the Possible Impact of Nanotechnology on Soldier Power

8 February 2001

by

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Compact Power Rationale

- **Computer/radio subsystem (including GPS) requires 45.1W**
- **Integrated helmet and sight subsystem requires 5.6W**
- **Weapon subsystem (laser rangefinder, laser aiming light, thermal weapon sight, etc.) requires 6W**
- **Micro-climate cooling requires >100W**
- **Weight of non-rechargeable batteries needed for a 72-hour mission is approximately 13 lbs *without micro-climate cooling***

Source: "Energy-Efficient Technologies for the Dismounted Soldier," Committee on Electrical Power for the Dismounted Soldier, Board of Army Science and Technology, NRC Press, 1997

The ‘Real-World’ Customer

Photo by Sarah Underhill

The Objective Warfighter

Regardless of the uniform, the Soldier will need reliable, affordable power

SPECIFIC ENERGY (Wh/kg)

SOURCE	SPECIFIC ENERGY (Theoretical)		SPECIFIC ENERGY (Practical)
Springs (watch)	0.25		0.15
Rechargeable Batteries			35-200
Primary Li/SO_2	1,400		175
Primary $Li/SOCl_2$	1,400		300
Zinc/air			300-400
TNT	1,400		N/A
Methanol	6,200		1,500-3,100
Ammonia	8,900	Energy	1,000-4,000
Diesel (JP-8 similar)	13,200	of	1,320-5,000
Hydrogen	33,000	Combustion	1,000-17,000
Nuclear	2,800,000		190,000

Batteries have many desirable properties (self-contained, convenient, familiar, quite safe, ...) and are likely to be key components of hybrid power systems

The User's Constraints

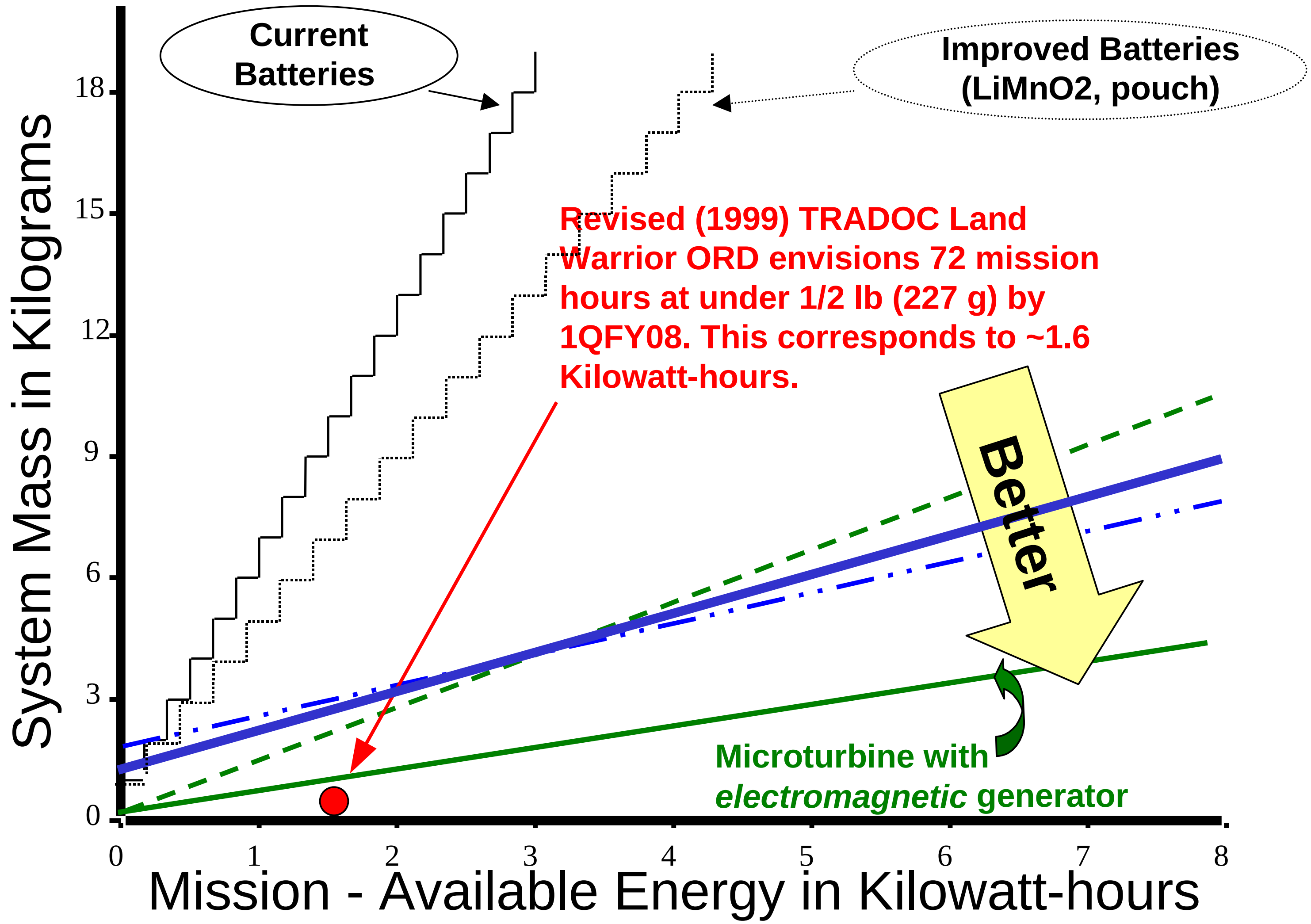
Mass-Energy Plots of Energy Conversion Systems

BA5590 Battery
1 kg device
50 W
170 Wh/kg (total)

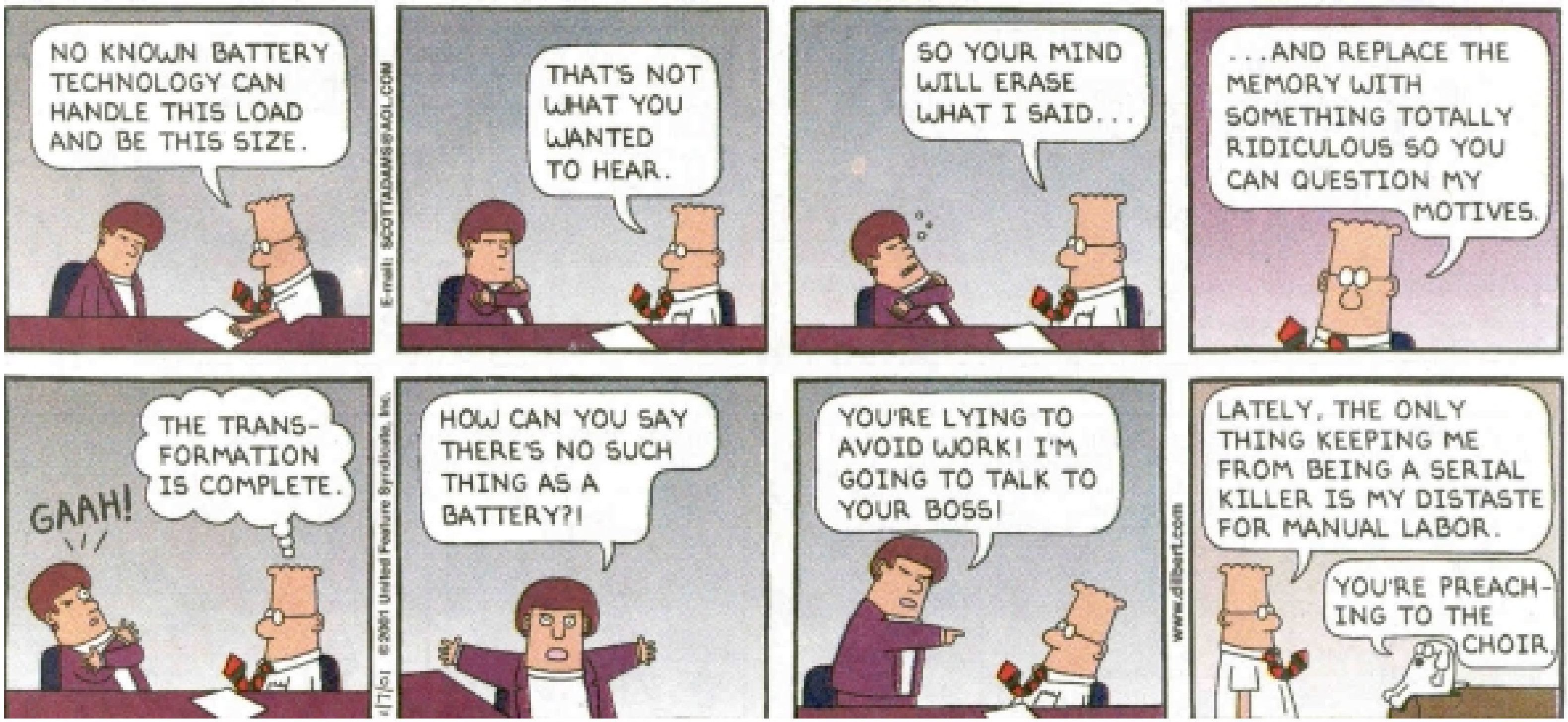
H_2/Air Fuel Cell
0.7 kg device
15- 25 W
1 kWh/kg (fuel)

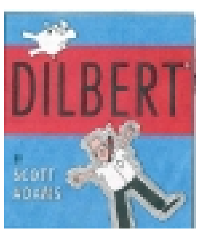
DMFC Fuel Cell
2 kg device
50-100 W
1.3 kWh/kg (fuel)

Micro gas turbine
<100 g device
50-100 W
.78 kWh/kg (fuel)



Everybody knows about batteries





From News & Observer, 8 Jan 2001

Advanced Energy Conversion Focus Areas

Electrocatalysts

Proton Conducting Membranes

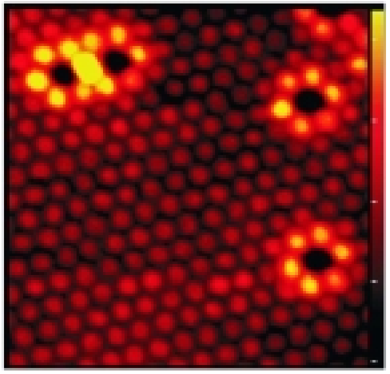
Microchemical Systems

Micro Turbine Power Systems

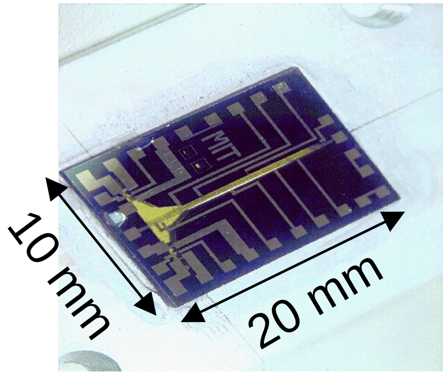
Hydrogen Sources/Storage

Hybrid Power Systems

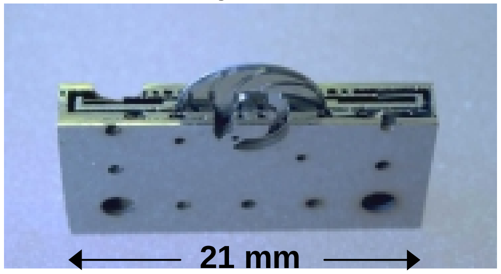
Thermophotovoltaics



Designed Catalyst - Norskov



Microchemical system - Jensen



Microturbine - Epstein

Examples in H_2/Air fuel cell evolution

- **<u>1992 - Analytic Power - SBIR:</u>**
- **15 W (on a good day)**
- **No fuel included**
- **5 pounds**
- **Short life**
- **Analytic Power now produces much better stacks**

- **<u>1996 - H-Power -DARPA/ARO:</u>**
- **40 W sustained**
- **90 Wh of stored hydrogen**
- **3.5 pounds**
- **Starts/runs reliably after 3+ years**
- **Stack is used in commercial products**

- **<u>2000?- Ball Aerospace -CECOM??:</u>**
- **Concept based on available technology**
- **15 W sustained, 25 W peak**
- **400 Wh of generated hydrogen**
- **2.2 pounds**

Relative Energy Density

The big challenge is the fuel supply

Fuel cells in field exercise, Oct 1999

Ball Aerospace PPS units supporting radio retrans link at Marines CAX 1/2-99 at the 29 Palms Marine Base on 19 Oct 1999 - support for development of these fuel cells came from DARPA, ARL-ARO/SEDD, SOCOM, CECOM, and the intelligence community.

Cost of operation - $26.18/day for fuel cells vs $900/day for BA5590 batteries

Jens K Norskov,et al, Danish Technical Univ

FIGURE 1: CATALYST DESIGN FROM FIRST PRINCIPLES

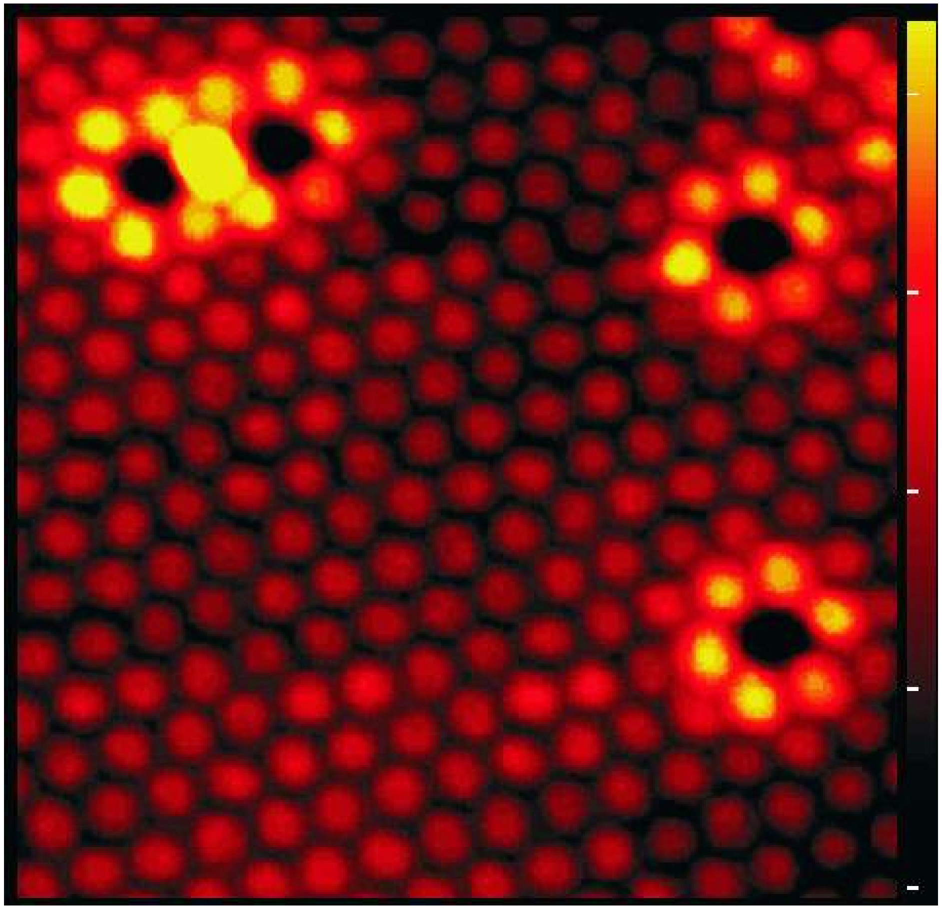


Figure 1: STM image of a Ni(111) surface with 2% of a monolayer of Au. The Au atoms appear black in the images. The Ni atoms next to the Au atoms appear brighter due to a change in geometry and electronic structure, indicating that the chemical activity of the Ni atoms may be modified by nearest neighbor Au atoms.

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http://www.fysik.dtu.dk/CAMP/hot0001.html

Jens K Norskov,et al, Danish Technical Univ

FIGURE 3: CATALYST DESIGN FROM FIRST PRINCIPLES

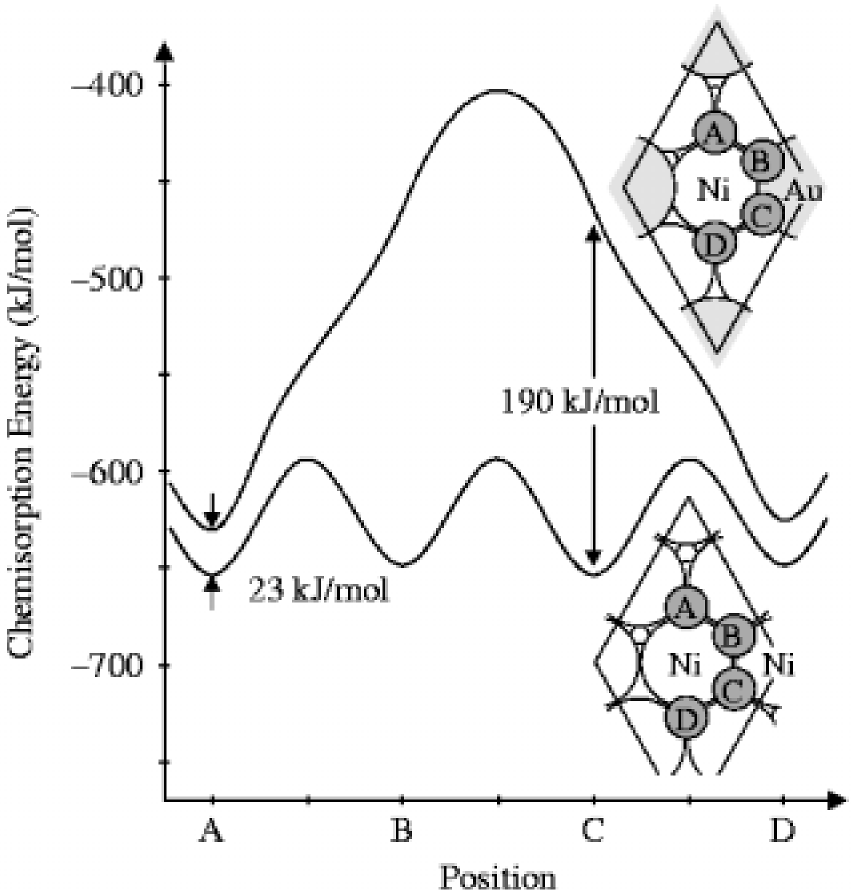

Figure 3: The calculated adsorption energy of a C atom on a Ni(111) surface as a function of position along the surface. The same energy function is shown above when one of the surface Ni atoms has been exchanged for a Au atom. The inserts show the geometry in the two cases

http://www.fysik.dtu.dk/CAMP/hot0001.html

Figure 4: Catalyst Design From First Principles

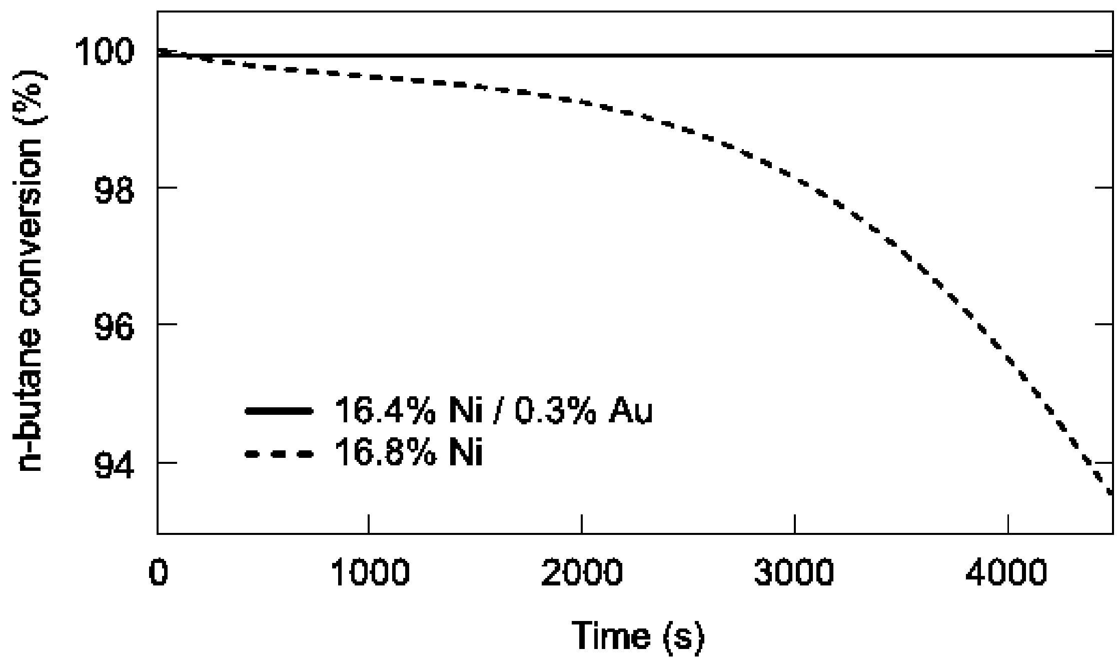

Figure 4: Conversion of n-butane as a function of time during steam reforming in a 3%n-butane-7% hydrogen-3% water in helium mixture at a space velocity of 1.2h-1. The dashed curve shows the n-butane conversion for the Ni and the solid curve is for the Au/Ni supported catalyst.

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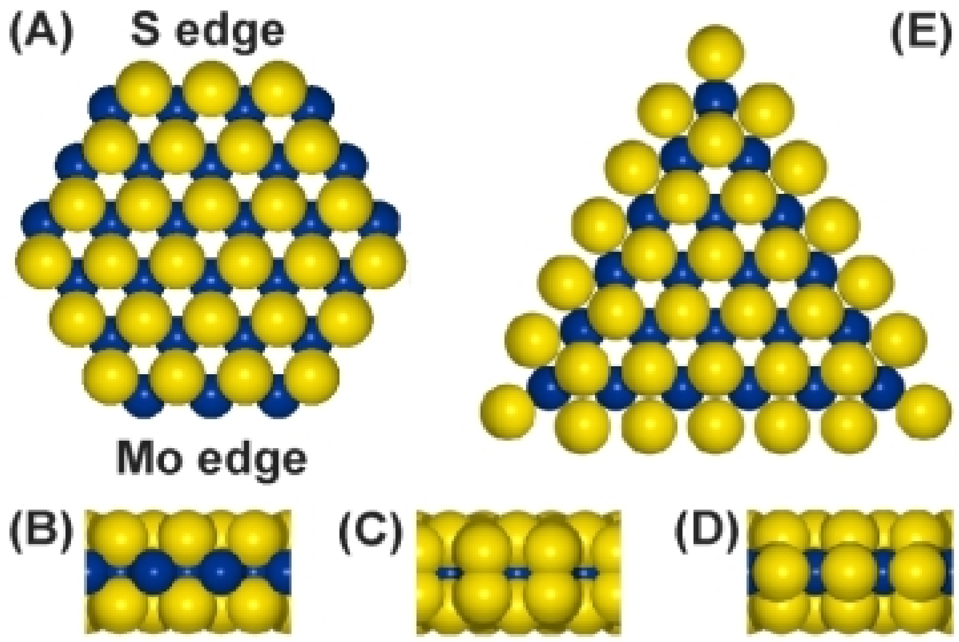
http://www.fysik.dtu.dk/CAMP/hot0001.html

ATOMIC-SCALE STRUCTURE OF SINGLE-LAYER MoS_2 NANOCUSTERS



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http://www.fysik.dtu.dk/CAMP

Danish Technical University

Atomic-scale structure of single-layer MoS_2 nanocusters

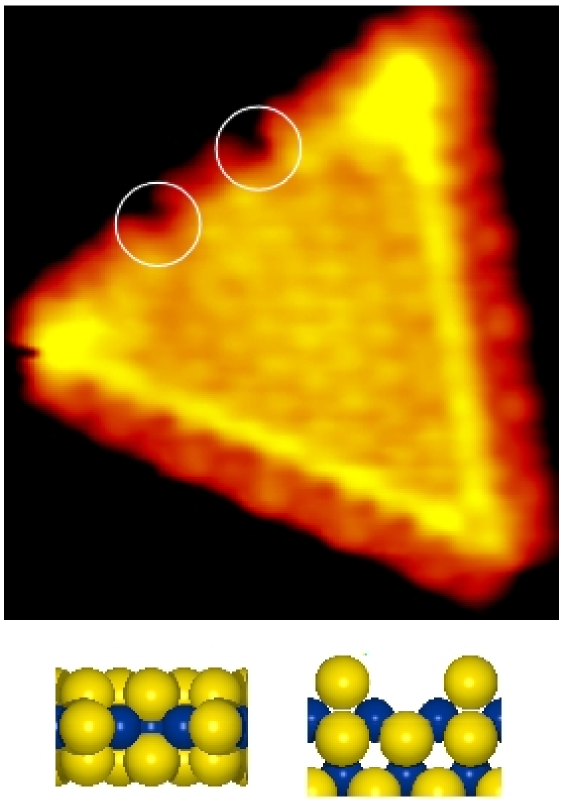
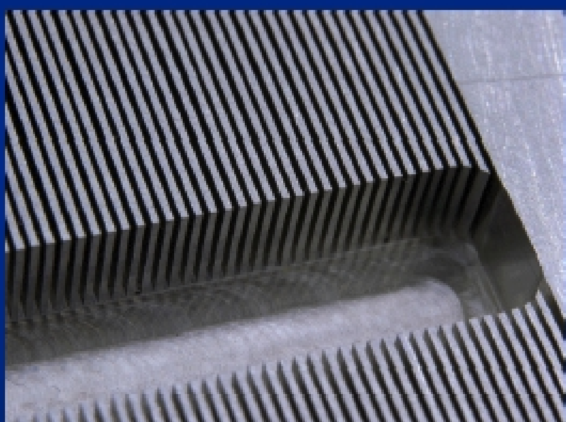


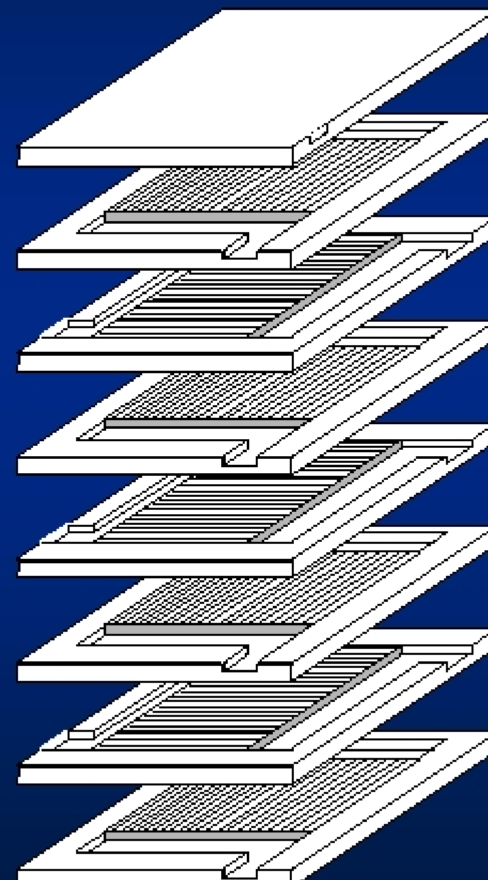
Figure 3: An atom-resolved image of a MoS_2 nanocluster exposed to atomic hydrogen which resulted in the formation o two S vacancies at the edges indicated by the white circles.

http://www.fysik.dtu.dk/CAMP

Energy Related Microreactor Efforts

- **Pacific Northwest National Laboratory (PNNL)**
  - **Proposed integrated fuel processing unit for hydrogen production from liquid fuel**
  - **Microchannel layered device**

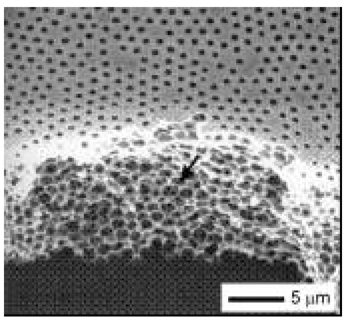




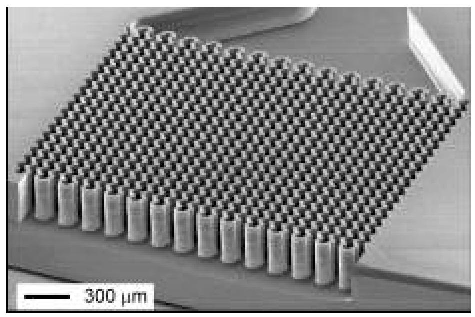
Pre-reformer

Need to get enough surface area/mass transfer to get enough reaction

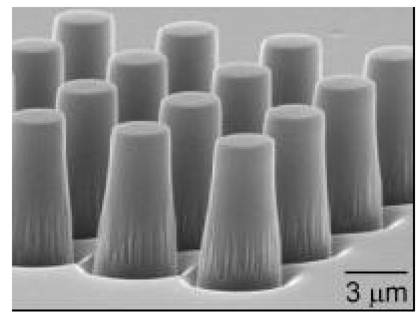
- Need to Build Appropriate Structures



Zia, et al



IMM

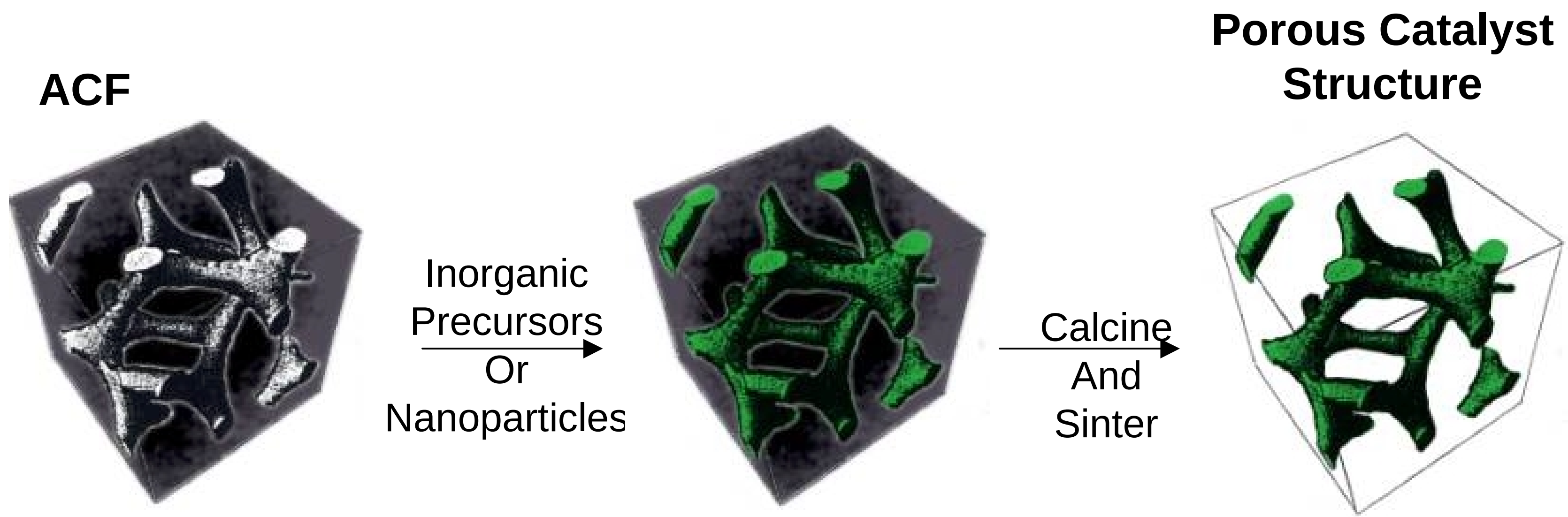


Adesida, UIUC

- Coat With Porous Structures to Hold Catalysts

Courtesy Prof Rich Masel, UIUC

Nanotechnology useful for porous coatings



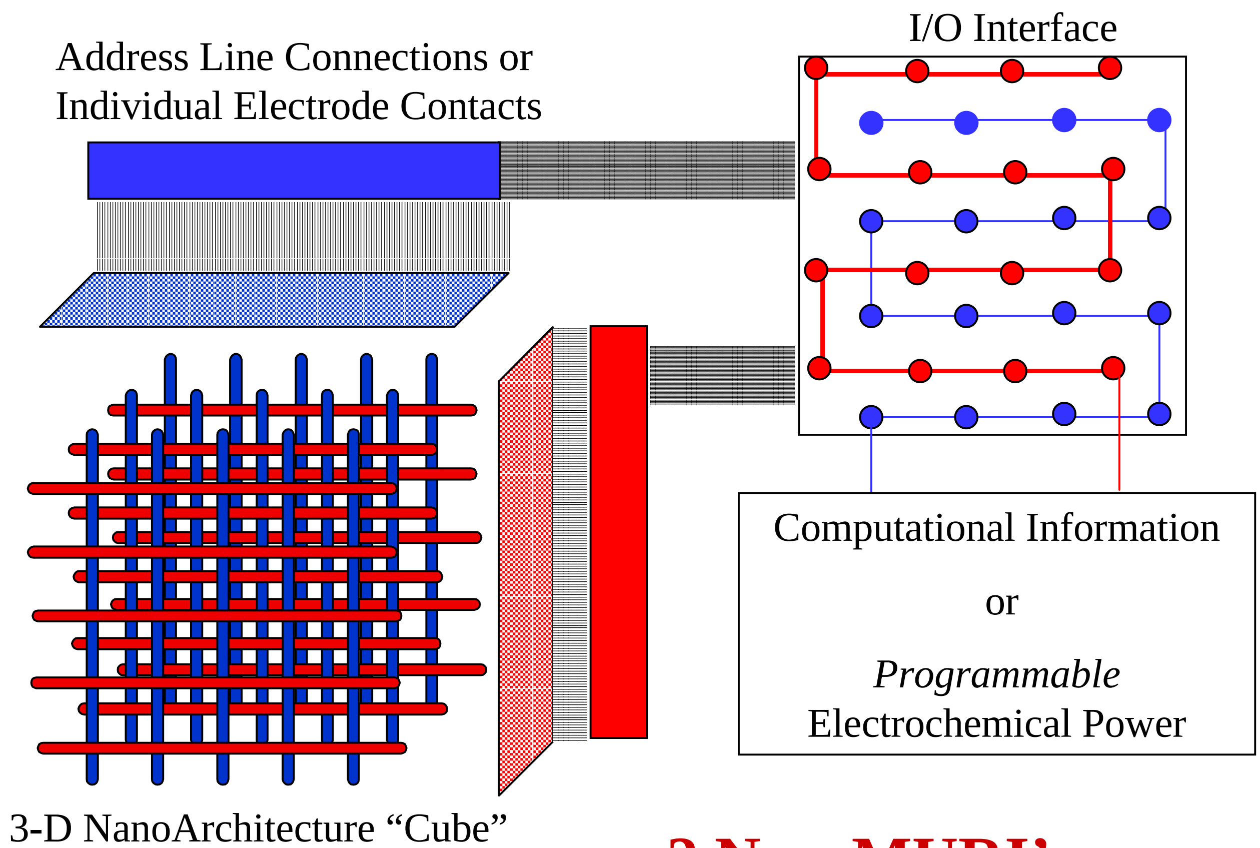
Surface=2000 m²/gm

Courtesy Jim Economy, UIUC

FY01 Multidisciplinary University Research Initiative (MURI)

3-D NanoArchitectures (D^3NA) for Future Electrochemical Power Sources

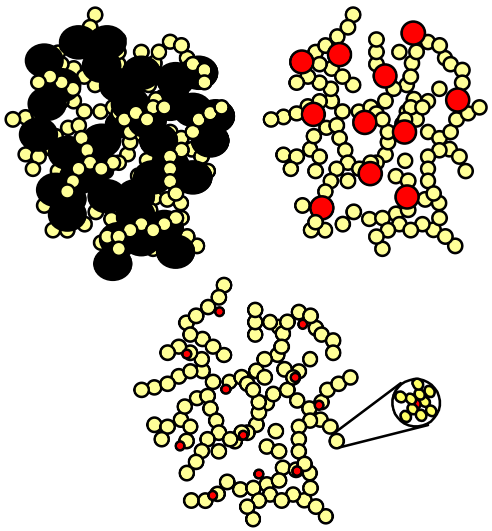
The 3-D Nanoarchitecture (D^3NA) program will develop the scientific underpinnings and the basic nanostructure building blocks for revolutionary approaches to electrochemical power sources. The umbrella concept relies upon the intelligent assembly of electroactive nanometer-scale structures to construct power modules of controllable size (submicron to multi-centimeter) in a manner compatible with microelectronics and microelectromechanical systems.

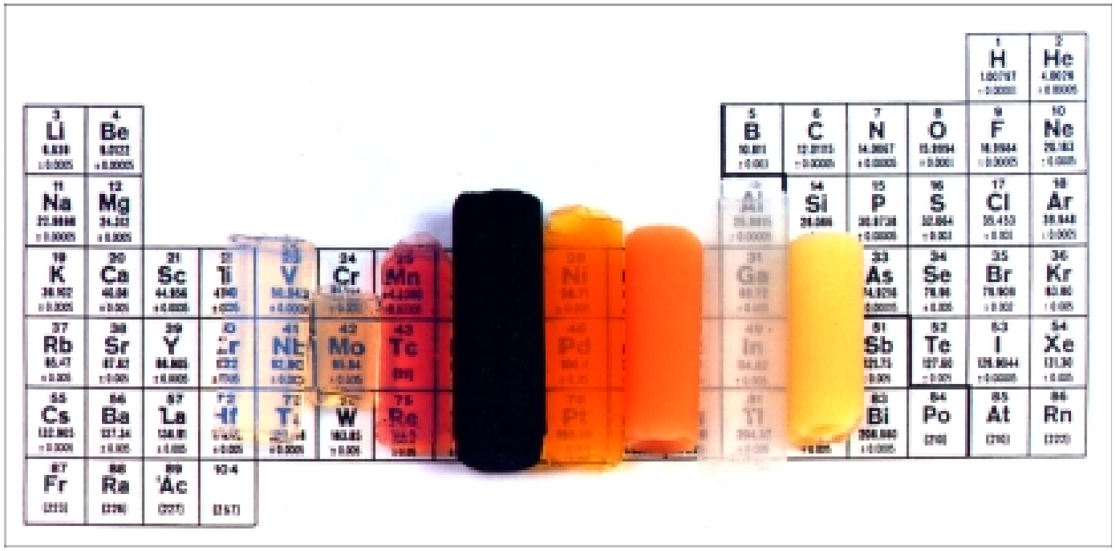


2 New MURI's announced 5 Feb

Electrochemistry ⇔ Nanoscience

Exploit nanoarchitectured electroactive structures & composites to enhance electrochemical performance of macro & microscale power sources while developing a comprehensive understanding of electron and ion transport at nanoscale dimensions.

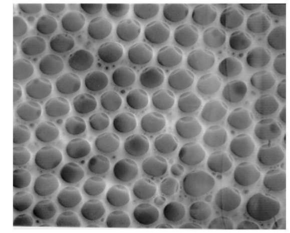




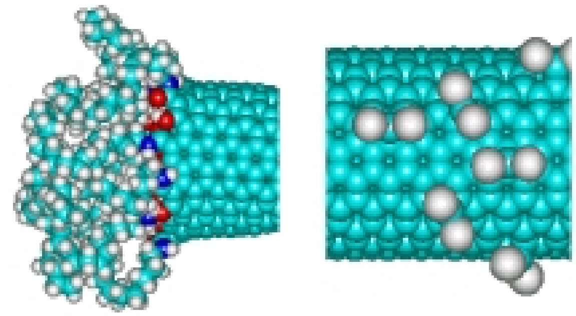
Anderson, Stroud, Morris, Merzbacher, Rolison, *Adv. Engineer. Mater.*

Nanoscience for the Marine 2010

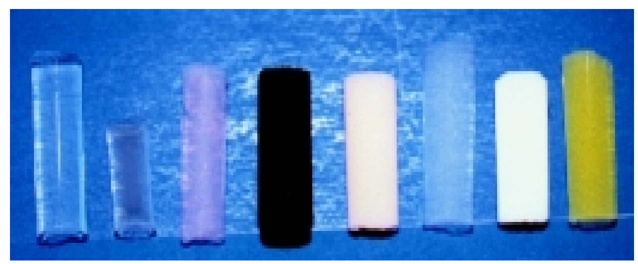
- NanoArchitectured Power Sources for Electronics & Pulsed Weapons
- Aerogel Nanocomposites for CBW Sensors & Filters
- Photonic Bandgap Face Shield Coatings for Laser Protection
- Carbon Nanotube for Lightweight Armor & Nanoelectronics
- Nanoporous Polymers for CBW & Environmental Protective Clothing



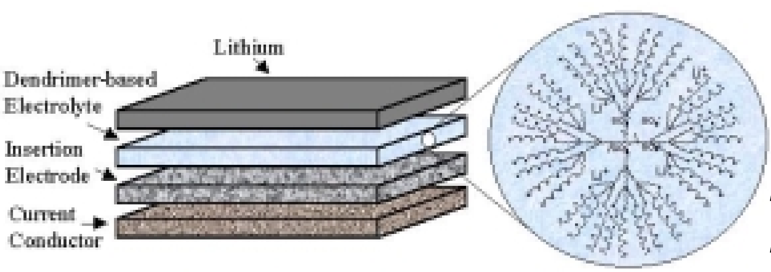
Photonic Bandgap Polymer



Derivatized Carbon Nanotubes

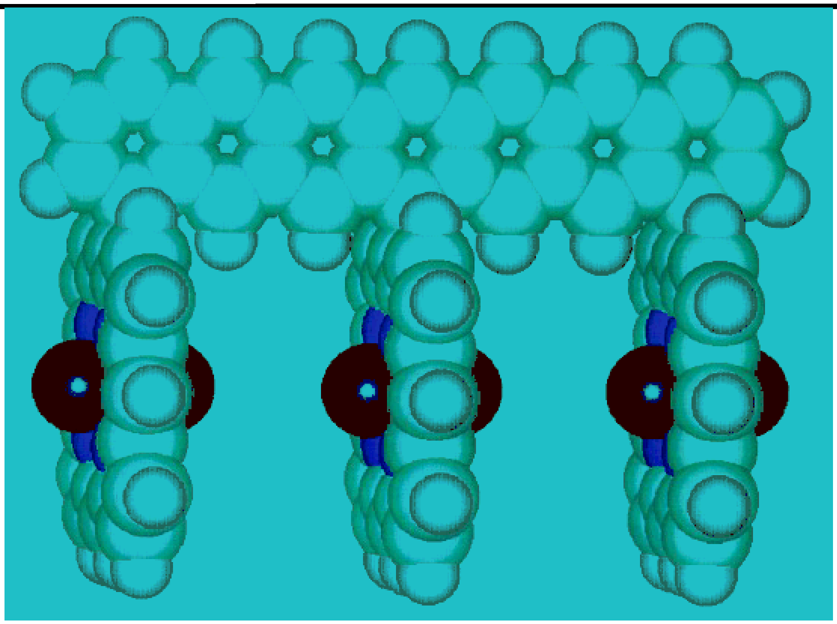


Silica Aerogel Nanocomposites



NanoArchitectured Lithium Battery

Low Dimensional Fast Ion Conductor
Larry Scanlon, AFRL/PO



PURPOSE

- Design and build a single lithium ion conducting polymer electrolyte with a high conductivity (~ 1 mS/cm) over a broad temperature range (+70 to -30°C) that is to be used in the construction of a rechargeable lithium polymer battery
- High electrode electrochemical stability especially at the lithium anode

APPROACH

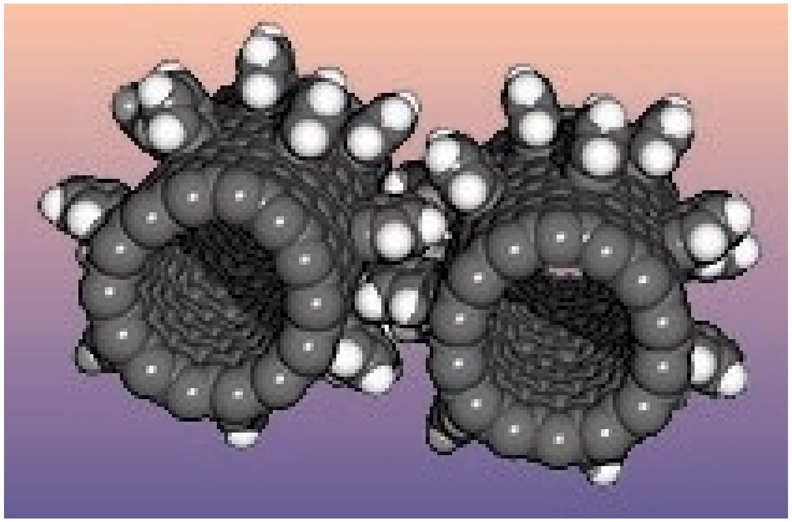
- Molecular orbital calculations were used to design a single Li-ion conducting channel with a constant solvent coordination sphere for lithium ions
- Unsaturated macrocyclic ring is important for achieving high lithium electrode/electrolyte interfacial stability

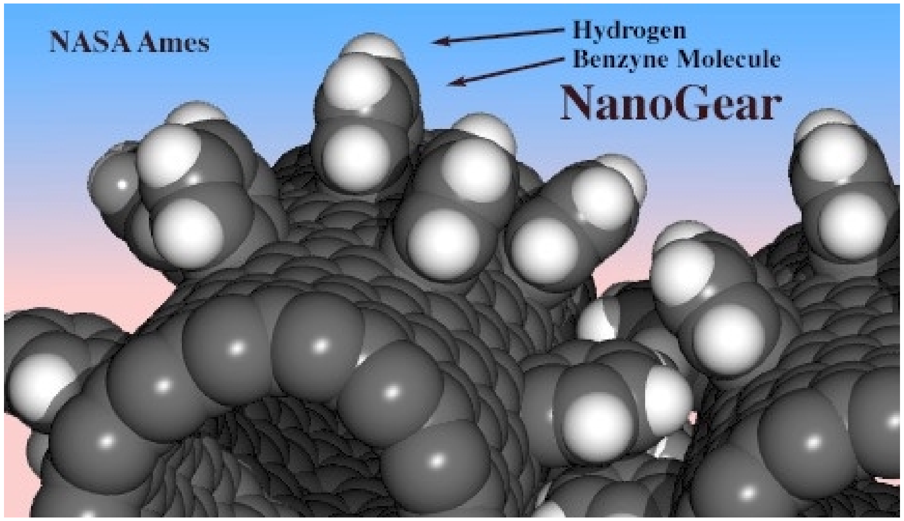
DOD TECH PAYOFF

- Dramatic reduction in percentage of battery weight on satellites and UAV
- Hybrid energy store for burst power applications

Molecular Dynamics Simulations of Carbon Nanotube Based Gears

Jie Han and Al Globus, MRJ, Inc., Richard Jaffe, NASA, and Glenn Deardorff, Sterling Software
NASA Ames Research Center, Moffett Field, CA 94035





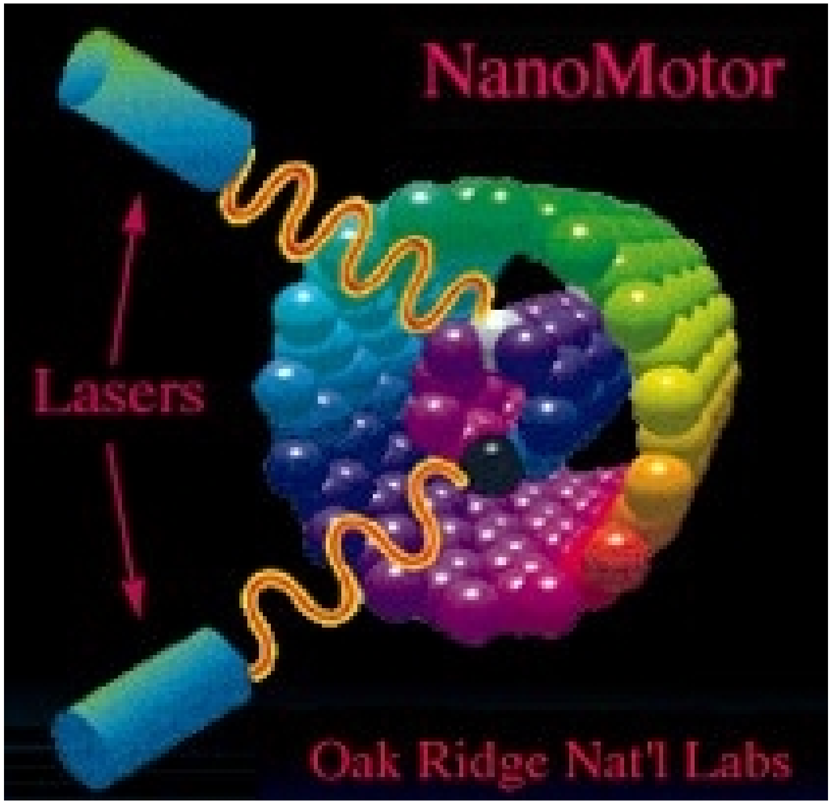
"Results suggest these gears can operate at up to 50-100 gigahertz in a vacuum or inert atmosphere at room temperature. The failure mode involves tooth slip, not bond breaking, so failed gears can be returned to operation by lowering temperature and/or rotation rate."

Abstract

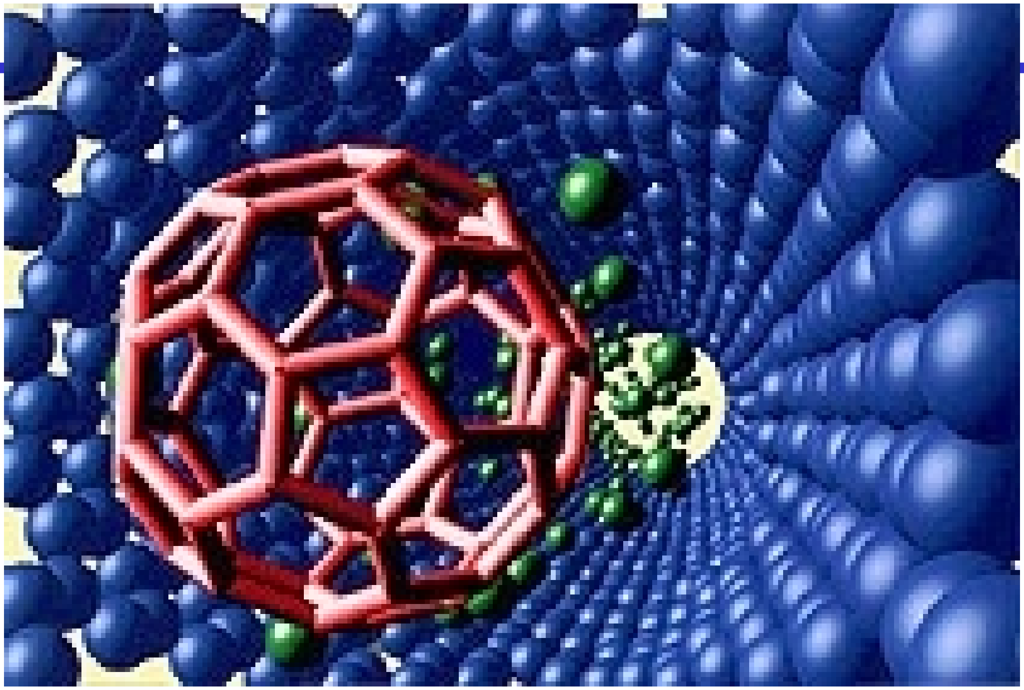
We used molecular dynamics to investigate the properties and design space of molecular gears fashioned from carbon nanotubes with teeth added via a benzyne reaction known to occur with C60 [Hoke 92]. A modified, parallelized version of Brenner's potential [Brenner 90] was used to model interatomic forces within each molecule. A Leonard-Jones 6-12 potential [Allen 87] was used for forces between molecules. One gear was powered by forcing the atoms near the end of the buckytube to rotate, and a second gear was allowed to rotate by keeping the atoms near the end of its buckytube on a cylinder. The meshing aromatic gear teeth transfer angular momentum from the powered gear to the driven gear. A number of gear and gear/shaft configurations were simulated. Cases in vacuum and with an inert atmosphere were examined. In an extension to molecular dynamics technology, some simulations used a thermostat on the atmosphere while the hydrocarbon gear's temperature was allowed to fluctuate. This models cooling the gears with an atmosphere. Results suggest that these gears can operate at up to 50-100 gigahertz in a vacuum or inert atmosphere at room temperature. The failure mode involves tooth slip, not bond breaking, so failed gears can be returned to operation by lowering temperature and/or rotation rate.

See Full paper at…...

http://www.nas.nasa.gov/Groups/Nanotechnology/publications/MGMS_EC1/simulation/paper.html



"The motors consisted of two concentric graphite cylinders (shaft and sleeve) with one positive and one negative electric charge attached to the shaft. Rotational motion of the shaft was induced by applying one or sometimes two oscillating laser fields. The shaft cycled between periods of rotational pendulum-like behavior and unidirectional rotation (motor-like behavior). The motor on and off times strongly depended on the motor size, field strength and frequency, and relative location of the attached positive and negative charges."



NanoPipes... Buckytubes, the multi-use nano component grow to different diameters and conduct electricity like copper, even better when stuffed with metal atoms. Larger tubes are big enough to pipe full sized C60 Buckyball molecules as in the illustration of the soccer ball shape (red) followed by Helium atoms (green), used as a transport "fluid". In addition to piping atoms and molecules, for perhaps a nanomachine construction sites, these tubes could be used as ultra small chemical reaction vessels.

Odds and Ends

- Fuel Cell interfaces
  - Fuel transport to catalyst
  - Ion mobility away from catalyst to electrolyte
  - Electron mobility away from catalyst to current collector
  - ‘Exhaust’ product transport away from catalyst (CO in DMFCs)
- Nanofluidics
  - Ion channels, biomimetics